

Total Maximum Daily Load  
For Siltation  
Arrowhead Pond  
Pottawattamie County, Iowa

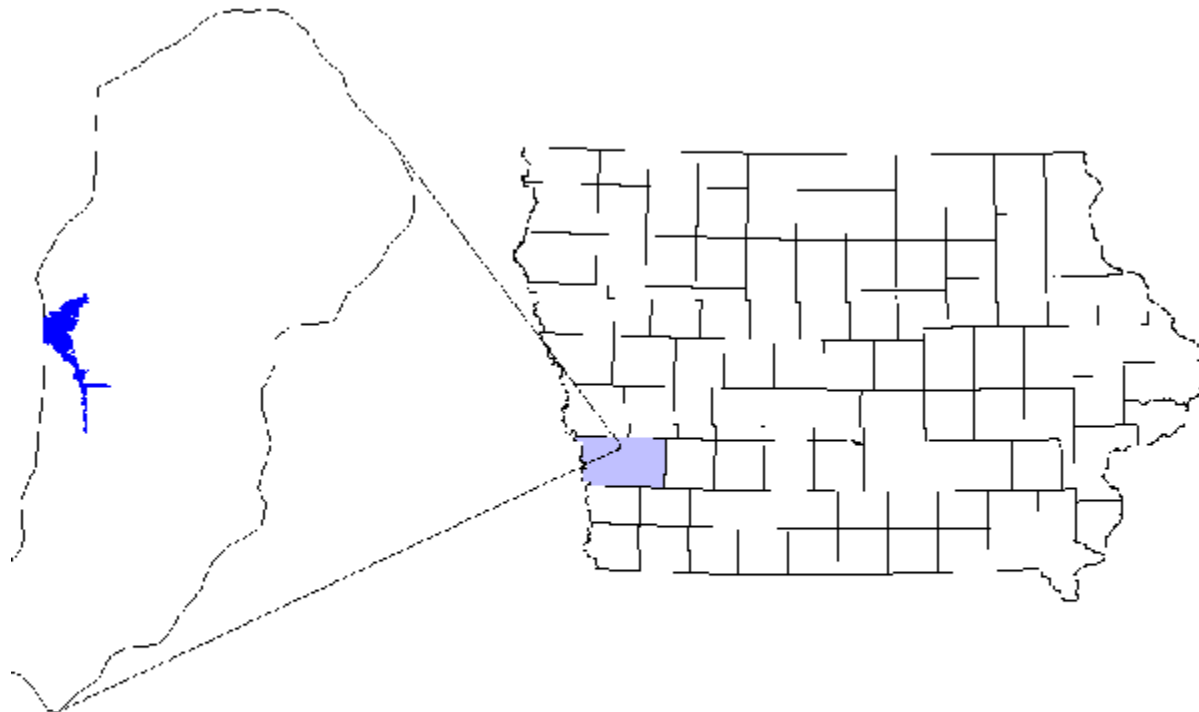
December 13, 2001

Iowa Department of Natural Resources  
Water Resources Section



TMDL for Siltation  
Arrowhead Pond  
Pottawattamie County, Iowa

Waterbody Name:	Arrowhead Pond
IDNR Waterbody ID:	IA 06-WED-00270-L
Hydrologic Unit Code:	HUC11 10230060030
Location:	Sec. 29, T77N, R41W
Latitude:	41 Deg. 26 Min. N
Longitude:	95 Deg. 35 Min. W
Use Designation Class:	A (primary contact recreation) B(LW) (aquatic life)
Watershed Area:	1048 acres
Lake Area:	Approx. 14 acres
Major River Basin:	Western Iowa River Basin
Tributaries:	Unnamed intermittent streams
Receiving Water Body:	Unnamed
Pollutant:	Siltation
Pollutant Sources:	Agricultural Nonpoint
Impaired Use:	Aquatic Life
1998 303d Priority:	Low



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## **1. Introduction**

The Federal Clean Water Act requires the Iowa Department of Natural Resources (DNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. The purpose of this siltation TMDL for Arrowhead Pond is to calculate the maximum amount of a sediment that the lake can receive and still meet water quality standards, and then develop an allocation of that amount of sediment to the sources in the watershed.

Specifically this siltation TMDL for Arrowhead Pond will:

- Identify the adverse impact that siltation is having on the designated use of the lake and how the excess load of sediment is violating the water quality standards,
- Identify a target by which the water body can be assured to achieve its designated uses,
- Calculate an acceptable sediment load, including a margin of safety, and allocate to the sources, and
- Present a brief implementation plan to offer guidance to Department staff, DNR partners, and watershed stakeholders in an effort to achieve the goals of the TMDL and restore the lake to its intended use.

Iowa DNR believes that sufficient evidence and information is available to begin the process of restoring Arrowhead Pond. The Department acknowledges, however, that to fully restore Arrowhead Pond additional information will likely be necessary. Therefore, in order to accomplish the goals of this TMDL, a phased approach will be used. By approaching the restoration process in phases, feedback from future assessment can be incorporated into the plan.

Phase I of the siltation TMDL for Arrowhead Pond will address the first target associated with achieving a reduction in the sediment load associated with the aquatic life impairment. Phase II will evaluate the effect that the sediment load targets have on the intended results. Included in Phase II will be monitoring for results, reevaluating the extent of the siltation impairment, and evaluating if the specific aquatic life impairment originally identified in the TMDL has been remedied. Ultimately, the intent of this TMDL is not to set in stone arbitrary targets, but restore the aquatic life that have been impaired. The phased approach allows DNR to utilize a feedback loop to determine if the initial sediment load target has been effective.

## **2. Description of Waterbody and Watershed**

### **2.1 General Information and Conditions at Time of Listing**

The Pottawattamie County Conservation Board purchased the land for Arrowhead Park in 1962 and Arrowhead Pond was subsequently constructed. Arrowhead Pond is located in the Loess Hill region of western Iowa, about 1.5 miles southeast of Neola, Iowa; has a surface area of 14 acres, a mean depth of 7 feet, a maximum depth of 12 feet, and a storage volume of 101 acre-feet.

Arrowhead Pond is entirely within the 147 acre Arrowhead Park, owned and managed by the Pottawattamie County Conservation Board. The lake provides facilities for boating, fishing, camping, picnicking, and hiking. The Park estimates usage is approximately 50,000 visits per year.

The Arrowhead Pond watershed has an area of approximately 1,048 acres and has a watershed-to-lake ratio of 75:1. This ratio is considered very high by the DNR, with an ideal ratio being 20:1.

Topography of the watershed is gently sloping to moderately steep (2-18%). Soils of the watershed are prairie-derived soils developed from loess or loess-derived sediments. These soils are generally composed of Ida, Napier, Hamburg, and Monona soils. These types of soils are described as having moderate to very fine granular structure, are very friable, and present severe erosion hazards. (USDA-SCS, 1989)

Average rainfall in the area is 32 inches/year, with the greatest monthly amount (5.5 inches) occurring in June.

In August 1983 the Pottawattamie County Conservation Board and the West Pottawattamie Soil and Conservation District submitted a proposal for the Arrowhead Lake Water Quality Management and Critical Area Treatment RC&D Plan, which was implemented starting in 1984, and completed by 1989. Essentially all of the conservation practices currently in place in the watershed were implemented during that time. This plan did not include shoreline stabilization measures.

In the 1994 Department of Natural Resources (DNR) biennial 305(b) water quality report, the fishable uses (Class B) for Arrowhead Pond were assessed as partially supported due to excessive sediment from agricultural sources, based on the best professional judgement of DNR Fisheries staff. This assessment was based on information collected during the 1992-1993 period. The sediment delivery to Arrowhead Pond was estimated based on the time at which the impairment was first noted in the 1992 reporting period, using the equation below, and then calculated again for 2001. Those numbers do not much different from each other. Results of those calculations are found in section 2.2.

Sediment delivery estimates were determined by using the Erosion and Sediment Delivery Procedure, Section I, Erosion Protection (USDA/NRCS, 1998). Part of that equation is to include "trapping efficiency" factors for areas where sediment is re-deposited as it travels through the watershed. For example, a factor for a "90% efficient structure" would be to multiply the sediment delivery through that structure by 0.10, representing that only 10% of the original load into the structure actually passed through. The remaining 90% of the sediment remained in the structure. Sediment Delivery Rate is taken from Chart 1, "Estimated Sediment Delivery for Landform Regions", using drainage area in acres. (USDA/NRCS, 1998). The following equation was used to calculate sediment delivery to Arrowhead Pond:

$$\text{Sediment Delivery (t/a/y)} = \text{Drainage Area} \times \text{Gross Erosion Rate} \times \text{SDR} \times \text{Trap Efficiency Factor}$$

Where:

- Drainage Area is the subwatershed in acres
- Gross Erosion is 3.45Tons/acre/year (RUSLE)
- SDR is the Sediment Delivery Rate = 65%
- TEF is the Trap Efficiency Factor = 0.10

Calculations were made for each subwatershed using this sediment delivery equation. A trap efficiency of 90% was calculated for each portion of the lake protected by silt dams above the lake. There are three subwatersheds within in the Arrowhead Pond watershed. Figure 1 in Appendix III shows the boundaries of each. There are three existing structures built above the lake on the northeast, southeast, and south sides of the lake. The sediment deliveries for each subwatershed were added together to obtain the total sediment delivery to Arrowhead Pond.

The primary impact of sediment to the aquatic life uses in Arrowhead Pond has not been clearly defined. Sediment impact to a fishery can include loss of habitat, interference with sight

feeding, and/or loss of macrophyte cover. Since this information is necessary to determine the target that would be most protective of the water body, this phased TMDL includes additional monitoring to determine those impacts.

## 2.2 Current Watershed Conditions

Estimates used “Predicting Rainfall Erosion Losses, The Revised Universal Soil Loss Equation (RUSLE)” Section I, Erosion Prediction (USDA/NRCS 2000) for sheet and rill erosion and “Erosion and Sediment Delivery Procedure”, Section I, Erosion Protection (USDA/NRCS 1998) for the sediment delivery factors. Pertinent calculations can be found in Appendix I. These two calculations are generally accepted in the agricultural community as simple and straightforward methods for determining gross erosion and its resultant delivery to a body of water. Using landuse and practices supplied by the Pottawattamie County Soil and Water Conservation District (Lundstedt, 2001), it is estimated that gross erosion is 3.45 tons/acre/year. The estimate is essentially the same for both 1993 when the water was first listed and now in 2001. There are three existing structures built above the lake on the northeast, southeast, and south sides of the lake. The sediment deliveries for each subwatershed were added together to obtain the total sediment delivery to Arrowhead Pond. The silt dams are estimated to be 90% efficient for the subwatersheds they protect, which reduces the total load to 236 t/y. The structures are maintained, and the northeast basin was cleaned out this summer. Approximately 8-10 ft of sediment was removed. The south structure is planned for maintenance next, followed by the east one.

The major contribution from sediment continues to be from shoreline and gully erosion within the park, but no actual data exists for shoreline or gully erosion at Arrowhead Pond. A study was conducted (Berg, 1980) at two Iowa artificial lakes, including Prairie Rose Lake and Big Creek Lake. Since Prairie Rose Lake has similar soil and weather conditions as Arrowhead Pond, findings from that study were used to make assumptions of an annual rate for shoreline and gully erosion losses. Those calculations and assumptions (included in Appendix I) estimate an additional 303 t/y were contributed from shoreline erosion around the lake, and approximately 81 t/y from gullies, making the total sediment delivery load to Arrowhead Pond 620 t/y. Note Table 3 in Section 8.2.

Land use data was collected in 2001 for Table 1.

**Table 1.** Current land use in Arrowhead Pond watershed.

Landuse	Area in Acres	Percent of Total Area
Cropland	640	61
Pasture & Hayland	357	34
Timber	31	3
Other (roads, etc)	20	2
Total	1,048	100

## 3. Applicable Water Quality Standards

The Iowa Water Quality Standards (IAC, 1996) list the designated uses for Arrowhead Pond as Primary Contact Recreation (Class A) and Aquatic Life (Class B(LW)). The State of Iowa does not have numeric water quality standards for siltation. In the 1994 Department of Natural Resources (DNR) biennial 305(b) water quality report, the fishable uses (Class B) for Arrowhead Pond were assessed as partially supported due to excessive sediment from agricultural sources, based on the best professional judgement of DNR Fisheries staff. This

assessment was based on information collected during the 1992-1993 period. The assessment of partially supporting of Class B (LW) has continued to be used in subsequent biennial reports.

Excess sediment impacts the Class B (LW) designated use by altering the physical and chemical characteristics of the lake so that a balanced community normally associated with lake-like conditions is not maintained (IAC 567-61.3(1)b(7)). The altering of the physical and chemical characteristics causes impairments of the following beneficial uses: 1) aquatic habitat; 2) spawning, reproduction and development; and, 3) sport fishing. In addition, siltation reduces food supplies by smothering benthic macro invertebrates, which are a food source for higher aquatic life. The specific impact of sediment to the aquatic life uses in Arrowhead Pond has not been clearly defined. Sediment impact to a fishery can include loss of habitat, interference with sight feeding, and/or loss of macrophyte cover. Since this information is necessary to determine the target that would be most protective of the water body, this phased TMDL includes additional monitoring to determine those impacts.

#### 4. Water Quality Conditions

Two Water Quality studies have been conducted at Arrowhead Pond. One was the Classification of Iowa's Lakes for Restoration Study by Iowa State University (ISU) (1994). Currently, in-lake water monitoring is being conducted as part of the Iowa Lakes Survey, which includes sampling three times per year for each of the field seasons 2000 – 2004.

**Table 2.** Summary of Pertinent Data from Water Quality Studies of Arrowhead Pond

Year	Total Suspended Solids	Chlorophyll a	Secchi Disc Depth	Phosphorus
1992	14.53 mg/l	24.5 mg/m3	0.6 m	0.089 mg/l
2000	(7.8, 22.3) 15.6 mg/l	(10, 48) 26 ug/l	(0.5, 1.3) 0.9 m	(213, 278) 250 mg/l

#### 5. Desired Target

The listing of Arrowhead Pond is based on narrative criteria. There are no numeric criteria for siltation applicable to Arrowhead Pond or its sources in Chapter 61 of the Iowa Water Quality Standards (IAC, 1996). Various proposals for how to develop numeric criteria are being considered, but no good numeric measure currently exists. An indirect measure of sediment is accomplished by demonstrating the linkages between excess sediment and the impacts to aquatic life. To assure that water quality standards for Arrowhead Pond will be met, this TMDL will incorporate two targets.

##### Target One

The Phase I target will deal with direct deposition of eroded sediment delivered to the lake. Because a direct link between excess sediment and impaired aquatic life has not been demonstrated in Arrowhead Pond, a specific sediment reduction value can not be determined at present. Phase I of this TMDL will be to maintain the sediment load from all sources at no more than the current levels. The resultant target sediment load for Arrowhead Pond is 620 tons of sediment per year.

##### Target Two

The Phase II target for this TMDL will be achieved when the fishery of Arrowhead Pond is determined to be fully supporting the Class B aquatic life uses. This determination will be accomplished through an assessment conducted by the DNR Fisheries Bureau in either 2001 or 2002. The DNR Fisheries Bureau will conduct an assessment of Arrowhead Pond in accordance with the Statewide Biological Sampling Plan protocol (Larscheid, 2001) by the end of the 2002 season to characterize the condition of aquatic life. IDNR Fisheries Bureau is using

this protocol to help develop benchmarks for fishery integrity in Iowa lakes. Sampling techniques for these surveys are outlined in "Standard Gear and Techniques for Fisheries Surveys in Iowa", 1995. This assessment will include growth, size structure, body condition, relative abundance, and species.

Arrowhead Pond will not be considered as meeting its designated uses until the second target is achieved. If the aquatic life target is achieved prior to the sediment delivery target, then the level of conservation practices implemented at the time of the assessment may become the baseline for the watershed. If however, after a reasonable time following the completion of the sediment delivery practices the aquatic life use has not been restored, then further study and practices may be necessary.

## **6. Loading Capacity**

The Iowa DNR has determined that maintaining the current sediment load delivered from all sources, assuming existing shoreline structures are repaired and maintained, will enable the lake to achieve water quality standards. The load capacity is 620 tons/year for the entire watershed on an annual basis.

## **7. Pollutant Sources**

Water quality in Arrowhead Pond is influenced only by non-point sources. There are no point source discharges in the watershed. Nonpoint source pollution is caused by material transported to the lake by runoff from the watershed. Gully, streambank/streambed, sheet and rill, and shoreline erosion can contribute significantly to poor water quality and deterioration of the lake. There is no streambank/streambed erosion in the Arrowhead Pond watershed. Shoreline stabilization had been conducted around the lake in the past, but most of it has degraded over time, and therefore is again a significant source of sediment. Although all land within a watershed contributes to sediment runoff, the main sources of this pollutant currently in the Arrowhead Pond watershed are gully erosion within the Park, and shoreline erosion around most of the lake.

## **8. Pollutant Allocation**

### **8.1 Point Sources**

There are no point discharges within the Arrowhead Pond watershed. Therefore, the Wasteload Allocation established under this TMDL is zero.

### **8.2 Non-Point Sources**

Production agriculture dominates the watershed of Arrowhead Pond. Because many erosion control practices have been adopted in the watershed, non-point source sheet and rill erosion accounts for very little of the sediment entering the lake. There are numerous gullies present along the shoreline adjacent to the camping areas on the south end of the Park, and under the footbridges across the south and east portions of the lake. Streambank/streambed erosion is not a factor, but shoreline erosion also contributes to sediment delivery around a major portion of the lake. These small gullies and shoreline problems as well as the high sediment delivery rate (65%) are all due to the nature of the soils present in the watershed.

Calculations were made for each subwatershed using the sediment delivery equation (Section 2.1). A trap efficiency of 90% was calculated for each portion of the lake protected by silt dams above the lake. There are three subwatersheds within in the Arrowhead Pond watershed. Figure 1 in Appendix III shows the boundaries of each. There are three existing structures built above



the lake on the northeast, southeast, and south sides of the lake. The sediment deliveries for each subwatershed were added together to obtain the total sediment delivery to Arrowhead Pond. There are at least twelve active gullies around the southern portion of the lake, adjacent to the camping areas, as well as ones under the bridges where they join the shore. Gullies are present on either end of the footbridges on both the east arm and the southern arm. Shoreline stabilization had been conducted on 3,080 ft around the lake in the past, but most of it has been degraded over time, and therefore is again a contributor. Calculations are difficult from this source, given the great number of variables involved. (See Appendix I)

The Load Allocation to support the target in this TMDL is 620 tons/year of sediment delivered to Arrowhead Pond. Maintaining current sediment delivered from shoreline and gully erosion levels, as well as maintaining gross erosion rates at no more than current levels, will maintain water quality while further studies are conducted. The shoreline allocation in Table 3 is a representation of the 3,080ft of earlier shoreline stabilization being repaired to the point that it is again effective. Table 3 shows, by subwatershed, the 2001 prediction of sediment delivery and the Load Allocation.

**Table 3.** Sediment Delivery Allocation to Arrowhead Pond (T/Y).

<b>Subwatershed</b>	<b>Acres</b>	<b>2001 Sediment Delivery</b>	<b>Load Allocation</b>
I	600	135	135
II	150	34	34
III	298	67	67
Gully Erosion		81	81
Shoreline		303	303
Total	1048	620	620

### **8.3 Margin of Safety**

An implicit margin of safety is recognized by virtue of the fact that the aquatic life use must be restored to Arrowhead Pond. The use of the dual targets of 1) maintaining current sediment delivery and 2) aquatic life assessment assures that the uses will be stabilized until more information is available. Further studies to determine how to achieve water quality standards will trigger revision of the TMDL, allocations, and/or further sediment source management approaches.

## **9. Seasonal Variation**

It is expected that the majority of all erosion in the Arrowhead Pond watershed occurs in the spring and early summer during periods of high rainfall when vegetative cover may be reduced. This TMDL recognizes that sediment loading and transport varies substantially from year to year as well as seasonally. In addition, sediment impacts are felt over longer timeframes, and predictions regarding those impacts can only be assessed over multi-year periods. Therefore, the Load Allocations in this document are appropriate when expressed as an average per year.

## **10. Monitoring Plan**

The DNR Fisheries Bureau will conduct an assessment of Arrowhead Pond in accordance with the Statewide Biological Sampling Plan protocol (Larscheid, 2001) by the end of the 2002 season to characterize the condition of aquatic life. Sampling techniques for these surveys are outlined in "Standard Gear and Techniques for Fisheries Surveys in Iowa", 1995. This assessment will include growth, size structure, body condition, relative abundance, and species.

In-lake water monitoring will be completed as part of the Iowa Lakes Survey, which includes sampling three times per year for each of the field seasons 2000 – 2004. That plan includes monitoring a number of parameters annually over a five-year period. Sampling includes total phosphorus in the water column, chlorophyll *a* in the lake to measure planktonic growth, total nitrogen, total suspended solids, and Secchi disc depth.

Bachmann cited a shortened life expectancy for this lake due to siltation. To help evaluate the true impact, bathymetry measurements should be taken by 2005. Additionally, pins studies should be conducted to better assess the rate of shoreline erosion.

## **11. Implementation**

The Iowa Department of Natural Resources recognizes that an implementation plan is not a required component of a Total Maximum Daily Load. However, the IDNR offers a two-phase implementation strategy to DNR staff, its partners, and watershed stakeholders as a guide to improving water quality at Arrowhead Pond. A phased TMDL is used to create an initial "plan of attack", so to speak, to address the impairment with available information. The initial first step towards meeting water quality standards is to maintain at no more than current levels the amount of sediment that will be delivered. The second one is to evaluate the impact of that action.

Phase I of this TMDL maintains at no more than current levels the sediment delivery to the lake. Phase II includes the restoration of the fishery to a level that fully supports the Class B aquatic life uses.

Phase I: A direct link between excess sediment and impaired aquatic life has not been demonstrated in Arrowhead Pond. Before a specific sediment reduction value can be determined, additional monitoring and assessment is necessary. Phase I of this TMDL will be to maintain the sediment load from all sources at no more than the current levels. This is only a temporary measure to begin the process of assessing the type and extent of the damage excess sediment has caused. It does not change current conditions, but is an attempt to assure that conditions in the watershed not degrade any further.

A sediment structure is the last line of defense in sediment delivery to a water body, and is not a long-term solution. As part of the cost share agreements for structures the recipient is required to maintain those structures for a predetermined amount of time. Although the structures in this watershed are maintained, and must be to protect the lake, this is an area with high erosion due to the nature of the soils present, and every effort must be made to manage erosion and runoff throughout the entire watershed. Numerous conservation practices have already been implemented in the Arrowhead Pond watershed. Virtually all the row cropland has been terraced. Roughly one third of the land is pasture.

There are a variety of BMPs that can help with erosion control management. They include tillage practices such as contour, cross-slope, no till, and conservation tillage; terraces; grassed waterways; grade-stabilization structures; conservation cover; filter strips; buffers and riparian zones; and wetland development. Each has an impact directly related to the conditions they address, and often need to be used in combination for maximum benefit.

The major source of sediment to Arrowhead Pond is the gully and shoreline erosion. The Load Allocation for this TMDL includes effectively re-establishing the 3,080ft of shoreline stabilization already conducted. The Pottawattamie County Conservation Board and the Arrowhead Park

Officers have been working on developing ways to mitigate the gully erosion around the lake and adjacent to the foot bridges. Funds to assist in the construction and development of best management practices in the watershed may be available through the Division of Soil Conservation and EPA Section 319 funding sources. Impaired waters may be given priority consideration in the allocation of 319 funds. One of the criteria used in consideration of 319 requests is whether the water body is impaired. Construction projects funded by Section 319 grants are subject to the provisions of the Endangered Species Act. Any projects within the watershed that utilize federal funds will consider any endangered species.

Phase II: The DNR Fisheries Bureau will conduct an assessment of Arrowhead Pond in accordance with the Statewide Biological Sampling Plan protocol (Larscheid, 2001) by the end of the 2002 season to characterize the condition of aquatic life. Sampling techniques for these surveys are outlined in "Standard Gear and Techniques for Fisheries Surveys in Iowa", 1995. This assessment will include growth, size structure, body condition, relative abundance, and species.

As stated in Section 4, at least maintaining the current sediment load is the most reasonable initial estimate to maintain the current average rate of deposition in the lake. This attempts to stabilize the impact on aquatic life. A phased TMDL is used to address the impairment with available information. The initial first step towards meeting water quality standards would normally be to substantially reduce the amount of sediment that will be delivered in the future. Since current information does not adequately allow for a load reduction to be determined, the first step in the case of Arrowhead Pond will be to maintain no more than current levels. The next step is to continue to assess conditions to support or to modify these initial targets. Arrowhead Pond will continue to be monitored under the Clean Lakes Study started in 2000 through the 2004 season. Phase II of this TMDL will be to evaluate that data and determine what further actions need to be taken.

## **12. Public Participation**

Public meetings regarding the procedure and timetable for developing the Arrowhead Pond TMDL were held on January 17, 2001, in Des Moines, Iowa; and on January 23, 2001 at Arrowhead Shelter near Neola, Iowa. Another meeting was held at the Shelter October 30, 2001 to discuss the draft document. Comments received, where appropriate, have been incorporated into this document.

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## 14. Appendix I

### PREDICTING RAINFALL EROSION LOSSES, THE REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE)

The equation is expressed as follows:  $A = RKLSCP$  where:  
A = average annual soil loss from inter-rill (sheet) and rill erosion caused by rainfall and its associated overland flow expressed in tons/ac/yr,

R = the factor for climatic erodibility,  
K = the factor for soil erodibility measured under a standard condition,  
L = the factor for slope length,  
S = the factor for slope steepness,  
C = the factor for cover-management, and  
P = the factor for support practices.

Example calculation from Arrowhead Pond Watershed:

A = ?  
R = 155 rainfall factor  
K = 0.35 erodibility factor (by soil type)  
LS = 2.23 length / slope  
CP\* = 0.060 [cropping factor] [practice factor (ex: 90% reduction, 10% of load)]  
\*combined C & P

$$\begin{aligned} A &= (155) (0.35) (2.23) (0.060) \\ &= 7.2586 \text{ t/a/y} \\ &= 7.3 \text{ /a/y} \end{aligned}$$

### GULLY EROSION

Approximate Unit Weight<sup>1</sup>

<u>Soil Textural Class</u>	<u>Dry Density (Lb/ft.<sup>3</sup>)</u>
Silt Loam	85

Gully erosion formulas:

Data and estimates from published soil surveys, laboratory data, and soil interpretation records are to be used where available. Parent materials, soil consistency, soil structure, pore space, soil texture, and content of coarse fragments all have influence on unit weight.

Where A = top width  
B = bottom width  
C = depth  
D = length  
E = soil unit weight  
F = head ward advancement  
G = average annual rate of sloughing or recession  
H = number of years

Gully development and volume computations are as follows:

$$\frac{2 \times C \times D \times G \times E}{2000} = \text{tons of eroded material}$$

Shoreline:

$$\frac{(\text{height of shoreline})(G)(\text{feet of shoreline})(E)}{2000} = \text{tons of eroded material}$$

There are essentially three different types of erosive action in Arrowhead Pond:

Gully, shallow shoreline, and vertical shoreline

Gully:

Almost all of the active gullies are located on the southern portions of the lake, except for those adjacent to the footbridges [12 gullies; 20-30 ft long; 4 ft deep; 0.37 ft (4") sloughing rate; 85 lb/ft<sup>3</sup> dry density; 1 year]

$$\text{Example Calculation: } \frac{(12)(4 \times 2)(1)(20)(85)}{2000} = 81$$

Shallow shoreline:

This includes almost all of the shoreline on the northern, north-eastern, and eastern portions of lake (roughly defined from the dam clockwise to the second footbridge on the eastern side of the lake). There is an estimated 3,480ft of shoreline in this category. Only approximately 400 ft have not had stabilization conducted. Although the impact is not uniform due to wind action, an overall loss can be used to describe movement. [400 ft of shoreline; 3 ft diagonal depth (above and below waterline); 0.16 ft sloughing rate; 85 lb/ft<sup>3</sup> dry density]

$$\text{Example Calculation: } \frac{(3)(0.16)(400)(85)}{2000} = 8 \text{ tons/yr}$$

Vertical shoreline:

The remaining sections of the shoreline traveling south from that footbridge around to the just south of the dam are essentially vertical is prone to undercutting due to minor amounts of wind produced wave action and freeze-thaw degradation. [3,126 ft of shoreline; aver 6 ft high; 0.37 ft (4") sloughing rate; 85 lb/ft<sup>3</sup> dry density]

$$\text{Example Calculation: } \frac{(6)(0.37)(3126)(85)}{2000} = 295 \text{ tons/yr}$$

## 15. Appendix II

**Figure 1**  
**Arrowhead Subwatersheds**

